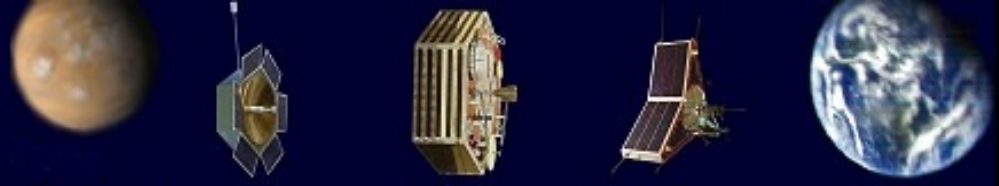


Bochum 66' Dish

Refurbishment, AMSAT Use and Achievements

Hartmut Päsler, DL1YDD (also: N1PU)

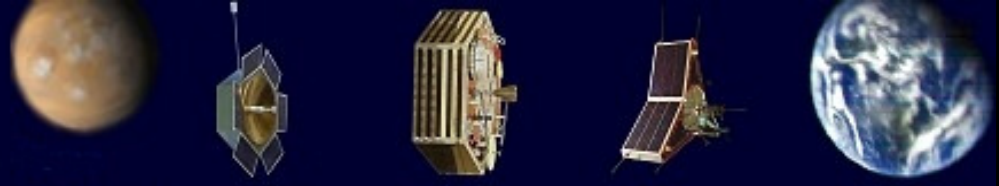
*Project Manager „P5A Ground Segment“
AMSAT-DL BOD member*



Why do we need a “big dish”: P5A

- If we lose contact to spacecraft, mission will fail
- “Failure is no option”
- Requirement: Keep contact even if s/c on omnis.



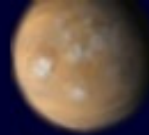


Requirements

- Positioning accuracy better 0.01°
- $15^\circ/\text{hour}$ (Planets), much faster for Earth satellites
- $\text{HF} > 65 \text{ dBi}@10 \text{ GHz}$, $T_{\text{Sys}} < 75 \text{ K}$
- If possible: remote operation

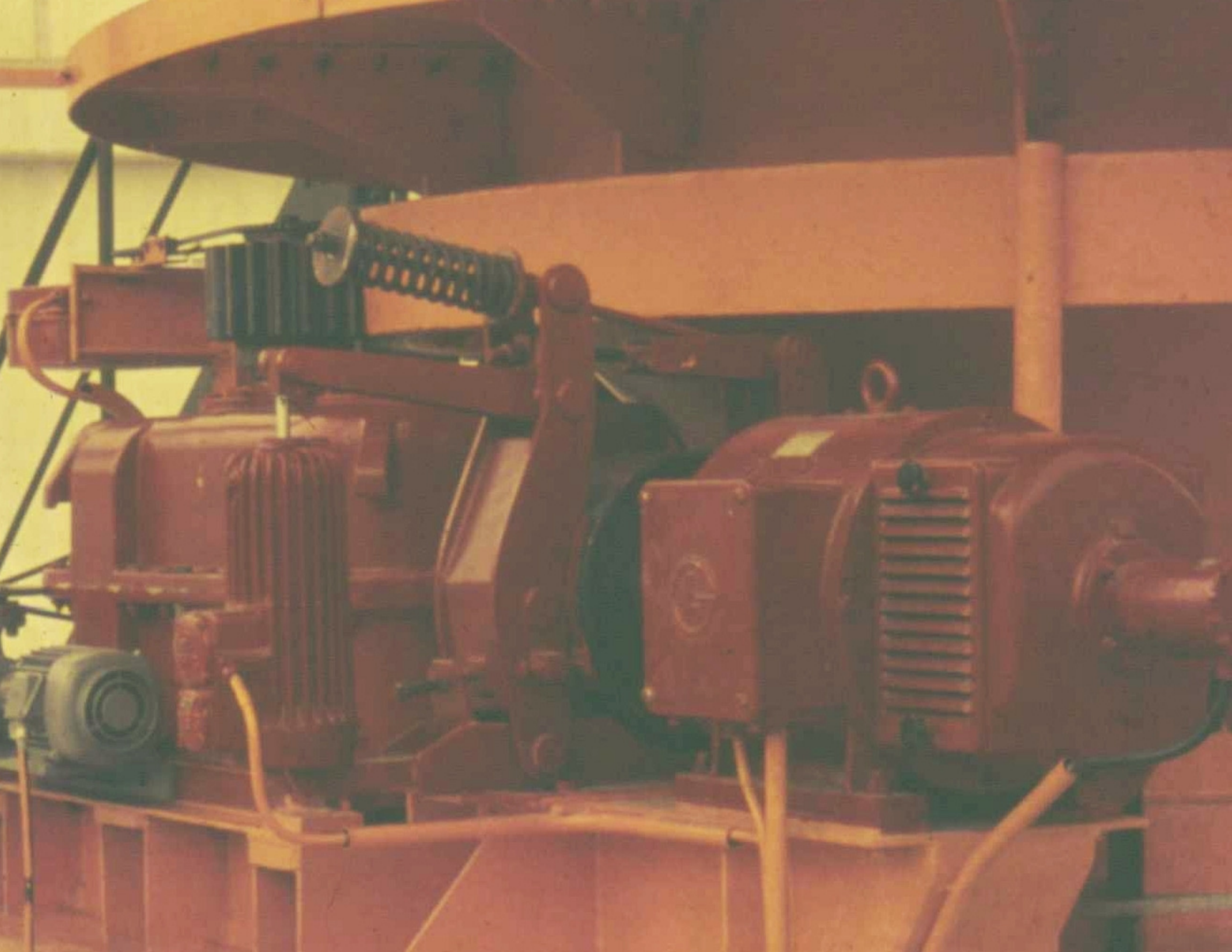
Or: To be successful, we must be able to point 140 tons moving mass to the edge of a match in 150 feet distance.

We must be able to hear a 5 W RF signal from 100 million miles distance (4000 times AO-40 apogee).



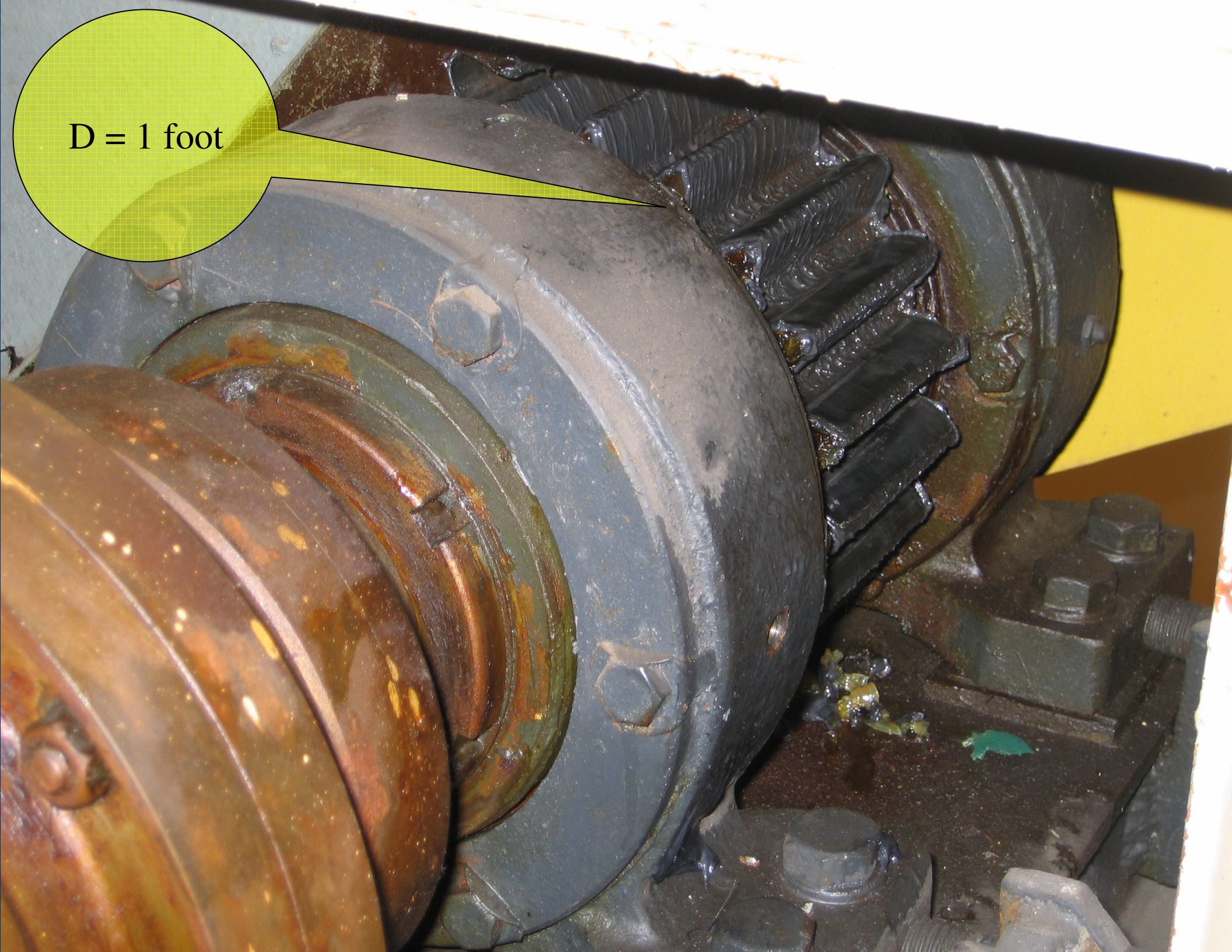
Inventory-taking

- 20 m/66' parabolic antenna, Status of RF equipment: unknown
 - 40 years old drive concept
 - huge DC motors
 - anchor winch gear boxes
 - giant mechanical power converters
 - analog control systems
 - ancient control “computer”
 - 40 year old RF equipment
 - Whole complex landmarked
 - User/Carrier: non-profit society, Hams!
-
-

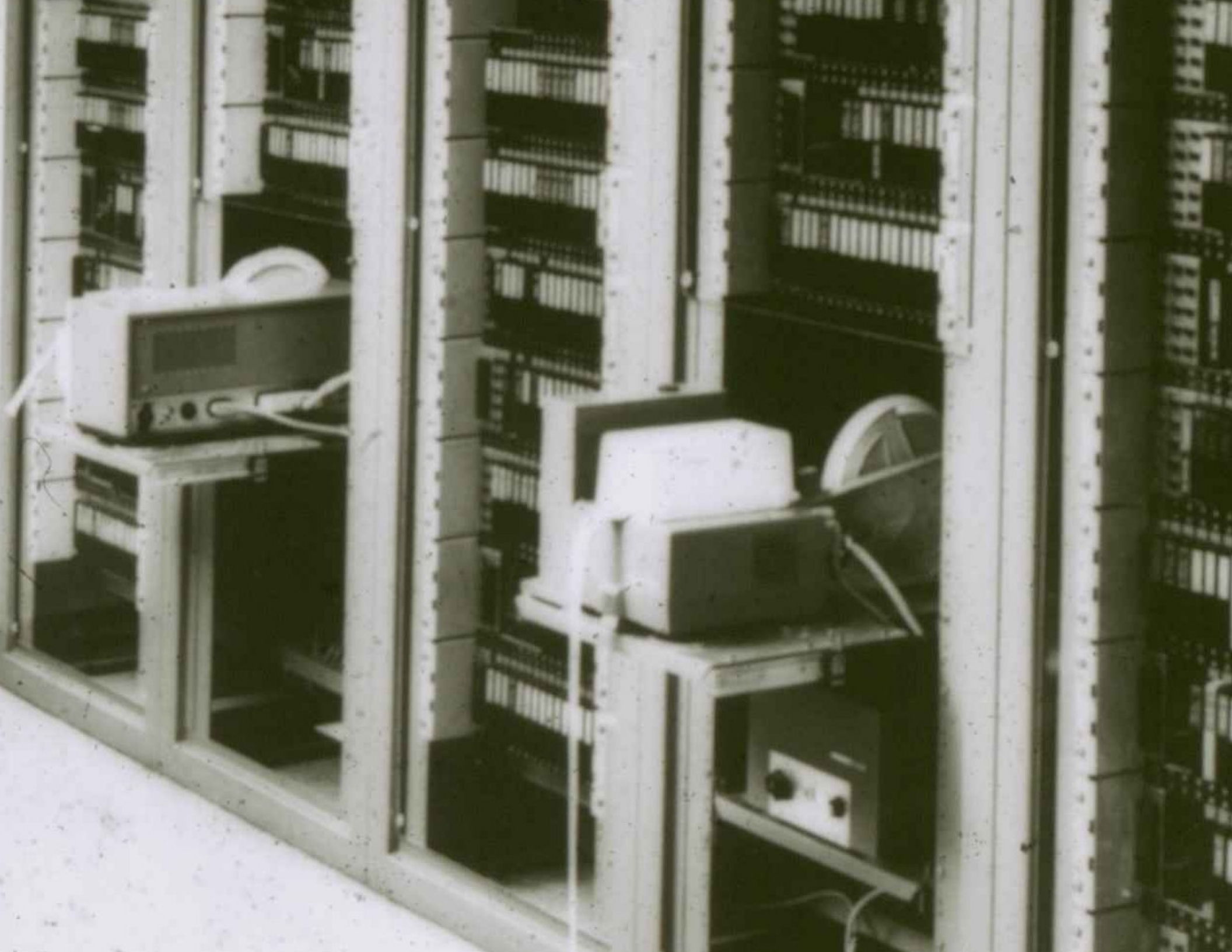




$D = 1 \text{ foot}$







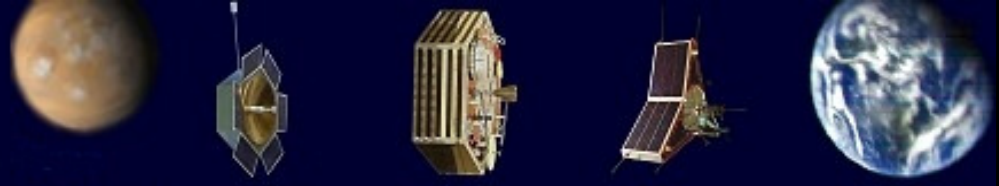


PID-Regler
V12F



PID-Regler
V12F

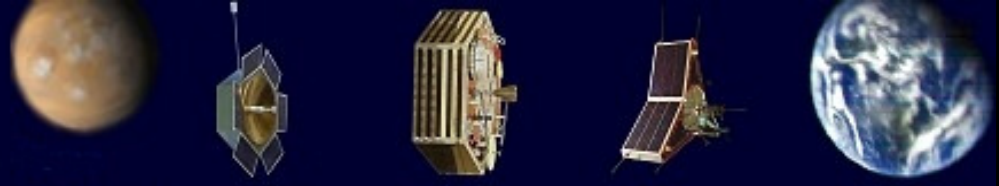




Perception:

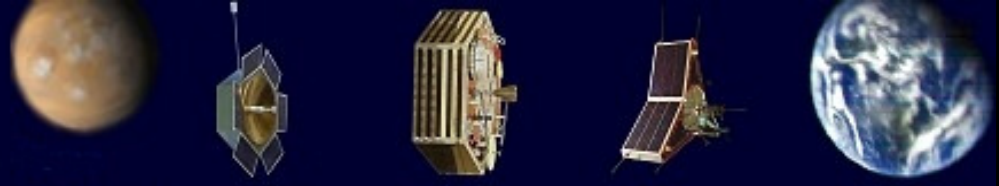
“Houston, we have a problem”

Requirements not
satisfiable with existing
equipment!



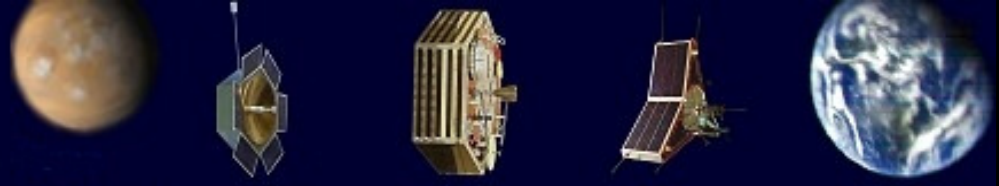
Things to change, rework:

- Mechanics
- Drives
- Control Systems
- Interfaces Computer - Mechanics
- Power Distribution System
- Calibration
- RF equipment



Solution: Mechanics

- use largely original mechanics
- Reconditioning by original contractor Krupp
- Status of mechanical system: good
- Gear boxes have backlash
- repair controls of subreflector
- add: oil pressure monitors
- add: emergency stop switches (how to stop 140 tons?)

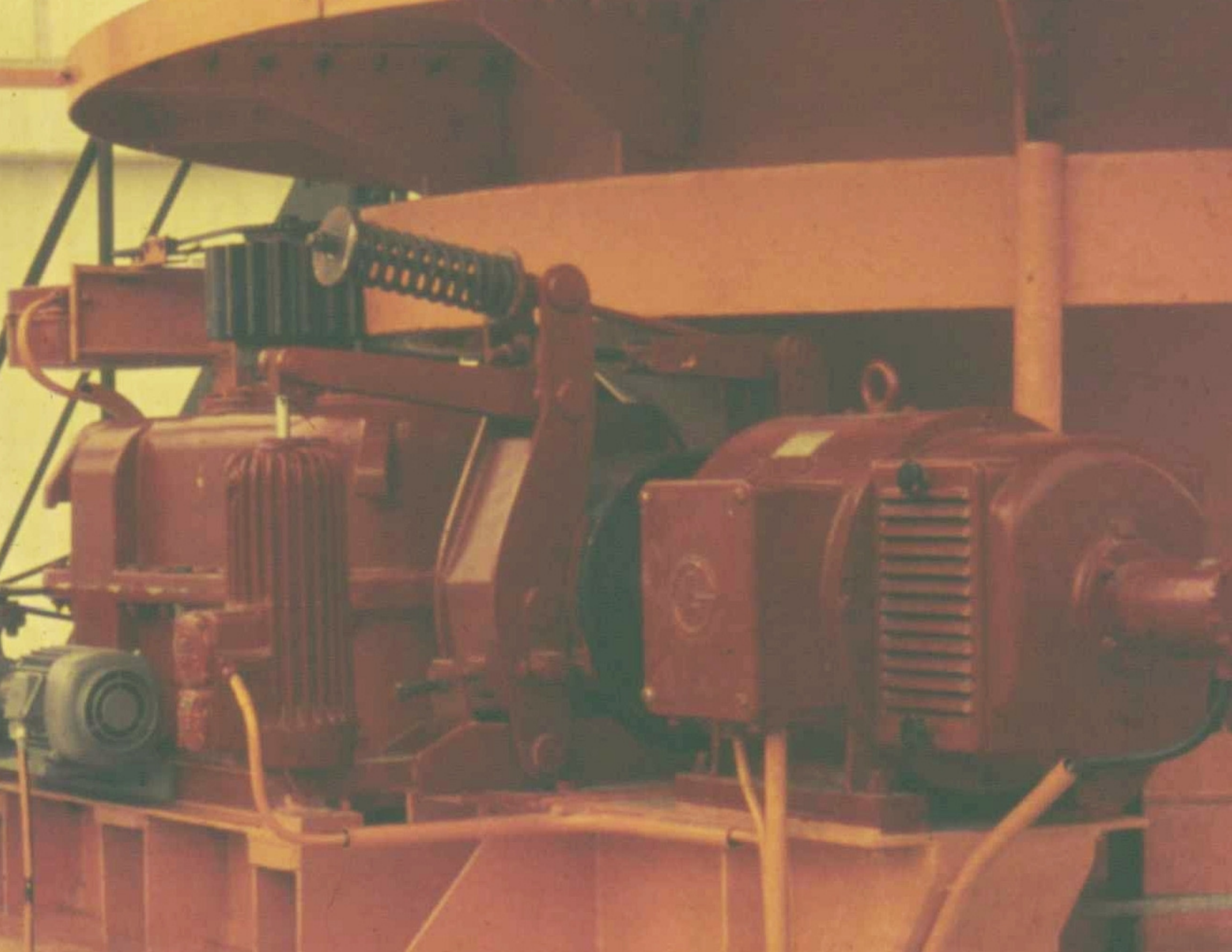


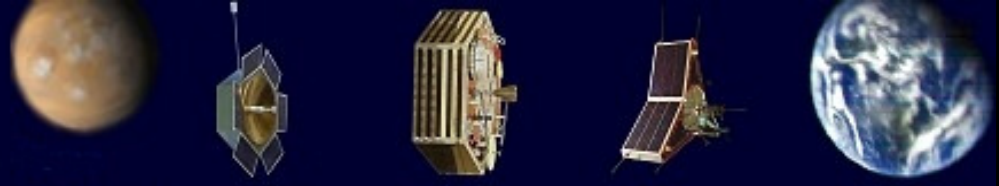
Solution: Drives

- Use of commercially available drive systems
- 2 servo motors per axis, incremental encoders
- “intelligent“ power amplifiers
- Communication via one RS-232 per drive
- Ballast resistors

Eurotherm/Mach4

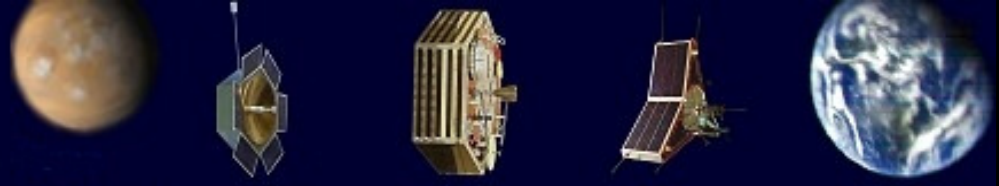






Solution: Control System

- numerical PID controllers for AZ and EL axis
 - Inputs, AZ and EL resp.
 - Setpoint from computer
 - Actual Position
 - Actual angular velocity
 - Generation of the correct torque to twist the axis (to compensate for backlash)
 - Torque limitation (AZ: 14000 Nm!)
 - Output: 2 torques AZ, EL resp.
 - Transmission to Eurotherm drive controllers
-
-



Solution: Control System

- simplified presentation
- Excerpt from problem list:
 - Complex dynamics of system
 - Tends to oscillate (140 tons!)
 - Torsion of axis (6 ' diameter!)
 - Limitation of torques (14000 Nm!)
 - Friction in bearings

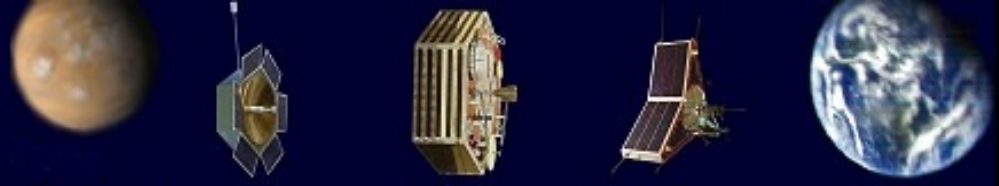
James Miller, G3RUH
Karl Meinzer, DJ4ZC



Solution: Interfaces

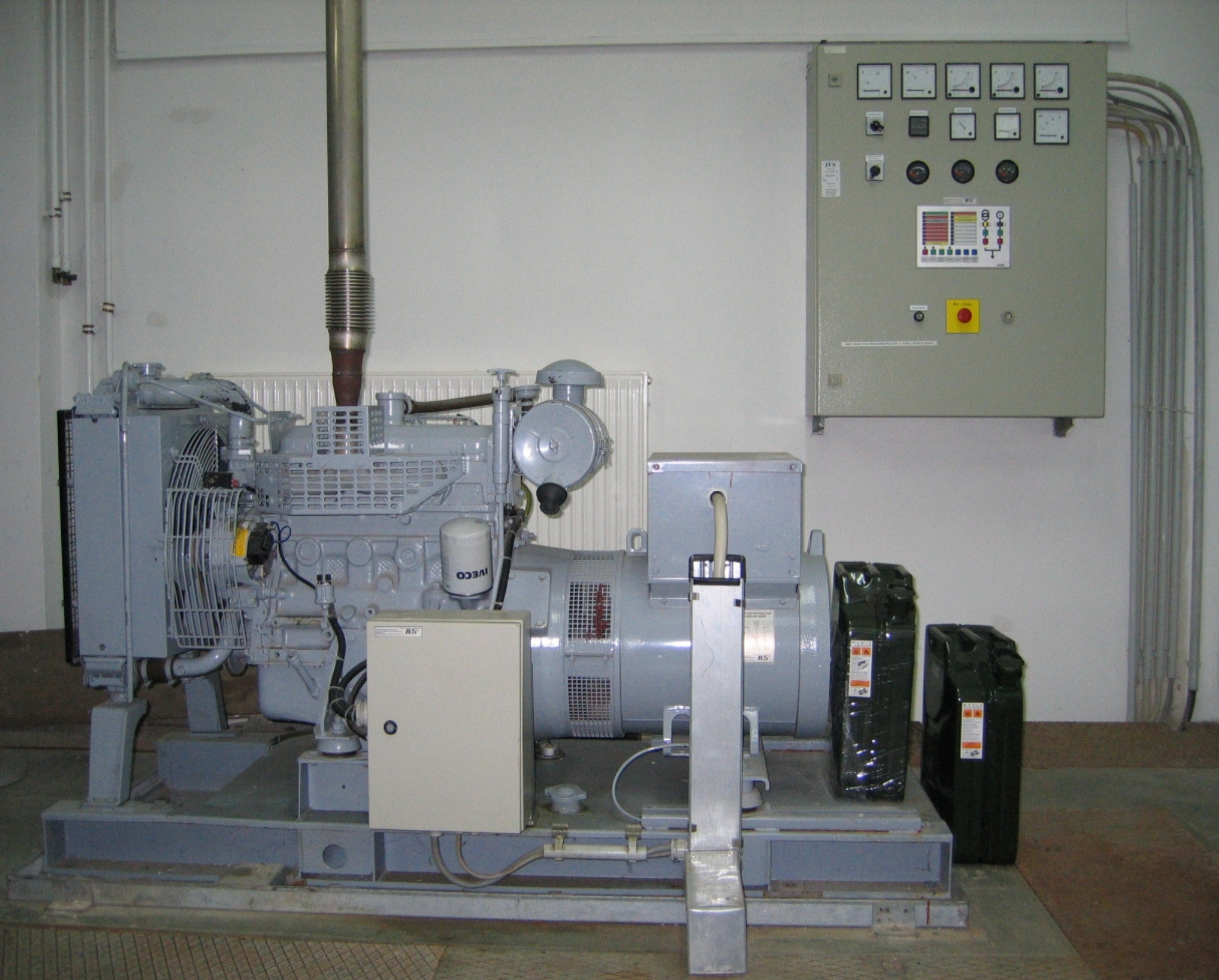
- Interface Box
 - Oil pressure
 - Emergency-Stop System
 - Reference marks
 - GPS (time)
- RS-232 Lines
 - 1 per motor (4)
 - Position and angular velocity
 - Set-point current for servo power amplifiers

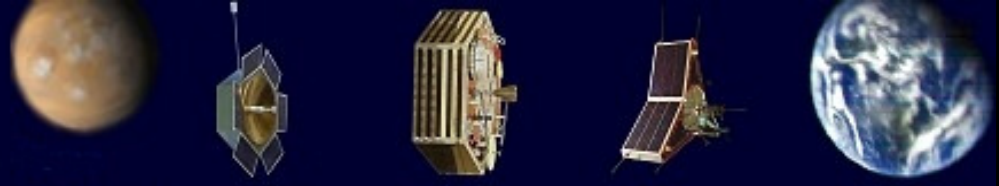




Solution: Power Distribution

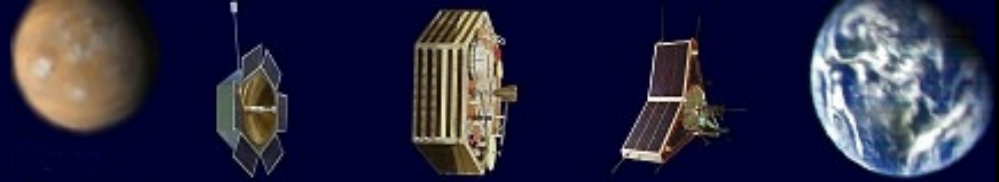
- Standard: Mains supply
- UPS Computer and Oscillators
- UPS Drive Controllers (SLAs, Calibration)
- Diesel generator (also for dome blowers)
- New Mains Power distribution system





Solution: Calibration

- Reference AZ: “Landmark” on dome wall
- Reference EL: precision spirit-level in focus room
- Numerical corrections:
 - Foundations tilted in 40 years ($\sim 0.1^\circ$)
 - Corrugation in AZ bearing (6' diameter bearing)
 - Droop of dish, depending on EL angle
- Use of digital angular encoders on motor shafts

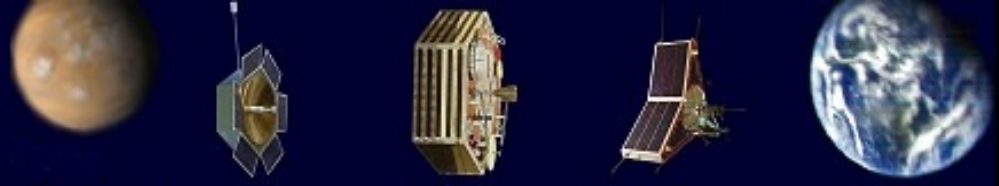


Key Technology: Software

- Without software: system useless!

James Miller, G3RUH





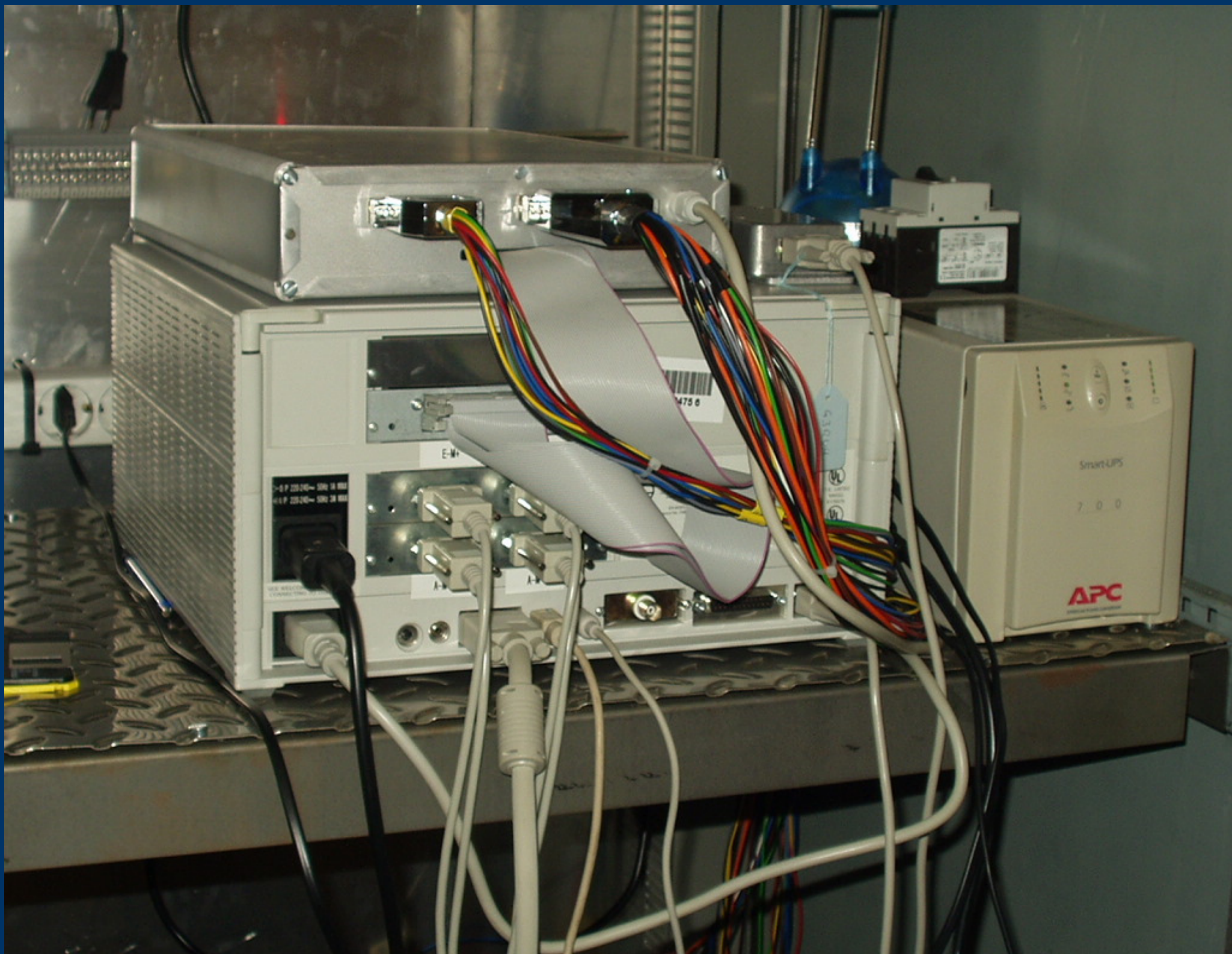
Software 66' antenna Bochum

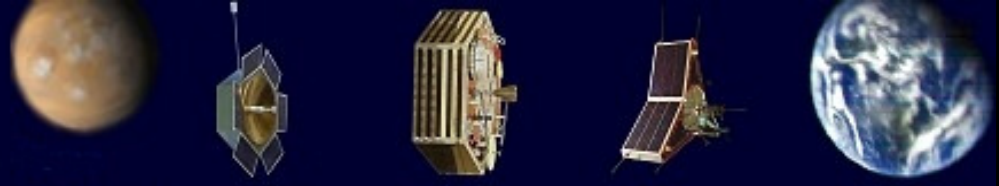
based on the presentation
„Servo Controller Computer & Software“
by James R Miller, G3RUH

*30 years of experience with satellite systems
Command station of AO-10, AO-13, AO-40
officially honored by JPL in their bulletin*









Software: special features

- very narrow beamwidth, 0.1° @ 10 GHz
- continuous tracking mandatory
- enormous size and moving mass
- no spare part service



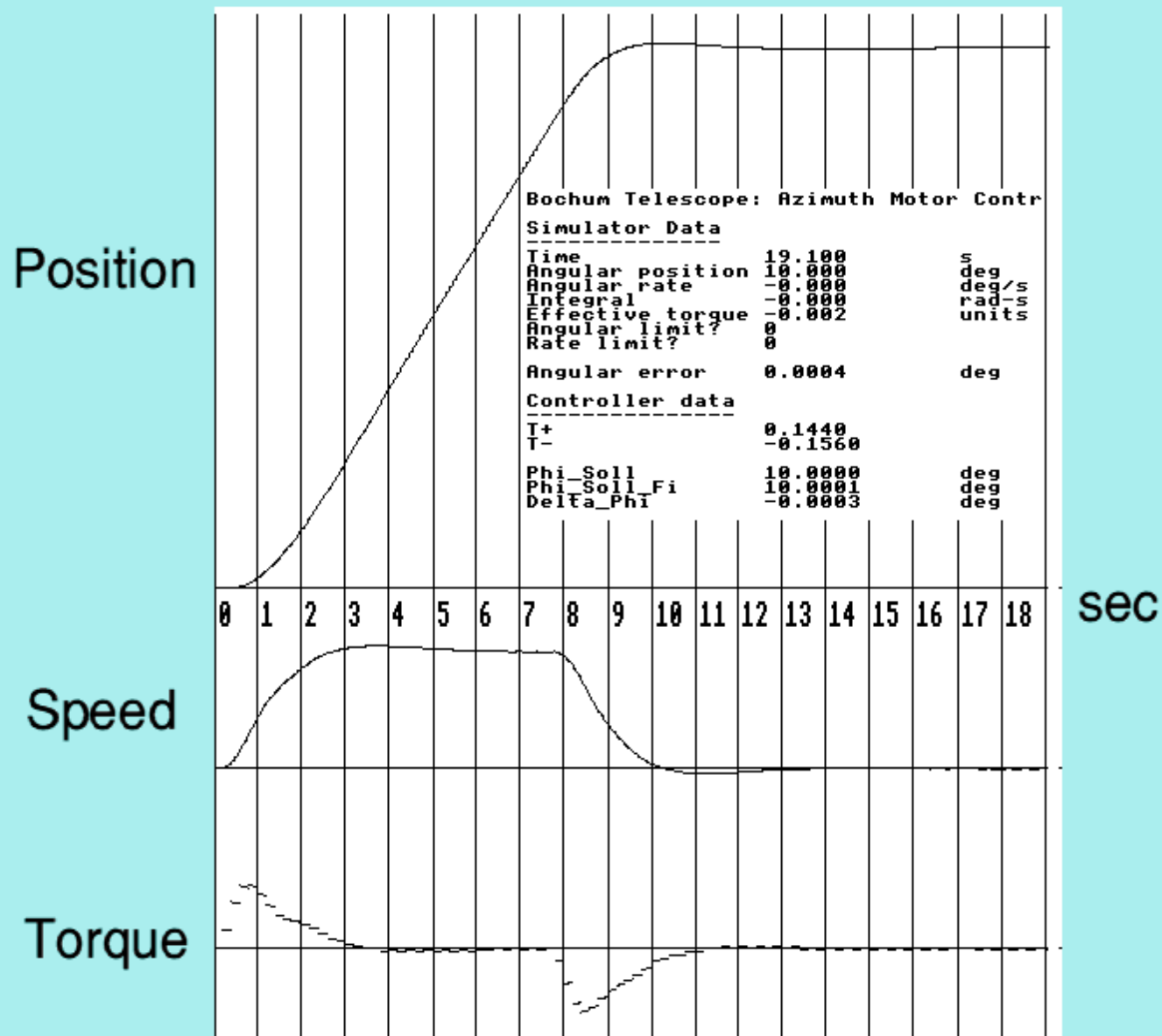
Software: Design

Creation of a simulation of the antenna physics

- Masses
- Friction
- Stiction
- Gearboxes
- AZ/EL shafts

Important for grasping of the system properties & test.

Control System Simulation





Software: Test

- Using the simulation
- At real antenna
 - Verification communications PC – drive controllers
 - Calibration an angular encoders
 - Live Test
 - 40 year old technology can be positioned to 10" or 0.003° – when assisted by modern software.

Sternwarte Bochum

Control Screen

```

Sternwarte Bochum      Radio Telescope Control      Version 3.4 by KM, HP, JRM
    2004 Sep 23 [Thu] 1437:58 utc                  Weather    25C  1015 mb

K  Almanac  Azimuth  Elev  Range  Doppler
   Object   deg      deg   M km   Hz/MHz
-----
1 Sun       235.25   24.06   150.073008   0.942 <<
2 Moon      120.96  -9.70    0.370798   0.767
3 Mars      238.32   24.60   397.422477   6.095
4 Rosetta   316.19  -3.59    72.859666   8.241
5 Cas A     30.66   30.07
6 Saturn    299.82   3.64  1409.188786  86.000
7 Cassini   299.54   3.78  1408.529031  87.418
8 Cyg A     73.70   41.96
9 AO-40     298.85 -17.07    0.058514  -4.511

Keys
-----
1 - 9      Track astro object
P/p        Change Planet
X/x        Change probe s/c
S/s        Change Star
TAB        Alt planet/probe/star
0          Go to Datum 18.9/0
F/f        Change Fixed object
H          Go to Horizon (EL=0)
A/E        Step or Rate to AZ/EL
<>        Step +/- 10°
R/r        Rate select +/-
SPACE      Hold position (Stop)
⇐ ⇨ ⇩ ⇧   Adjust offset 0.01°
SHIFT⇐⇨⇩⇧ .. .. 1.00°
RETURN     Zero offsets
T/t,L/l    Set temp,pressure +/-
Q          Quit
-----

Data from User
-----
AZ_demand      235.2607 °
AZ_offset      1.14 °

Data from controller
-----
AZ_Phi_Soll    236.4007 °
AZ_Phi_Soll_Fi 236.3930 °
AZ_Phi_Ist     236.3932 °
AZ_Delta_Phi   -0.0001 °
AZ_Integral    0.001
AZ_M_plus      0.203
AZ_M_minus     -0.100

Data to/from Eurotherm
-----
Position counter M+ 0xF9216C0C
Position counter M- 0xF9216C0C
Motor current M+    14 /70
Motor current M-    -7 /70

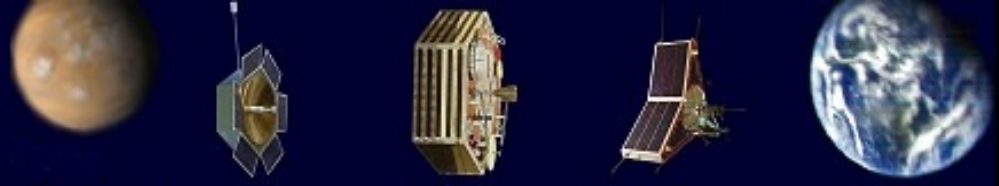
Run time 0:0002:46

Data from User
-----
EL_demand      24.0546 °
EL_offset      0.00 °

Data from controller
-----
EL_Phi_Soll    24.0972 °
EL_Phi_Soll_Fi 24.1002 °
EL_Phi_Ist     24.1003 °
EL_Delta_Phi   -0.0001 °
EL_Integral    -0.002
EL_M_plus      0.200
EL_M_minus     -0.100

Data to/from Eurotherm
-----
Position counter M+ 0xFE1FCB7C
Position counter M- 0x01E03484
Motor current M+   -13 /70
Motor current M-   -7 /70

Time used: 3 cs of 10 cs
  
```

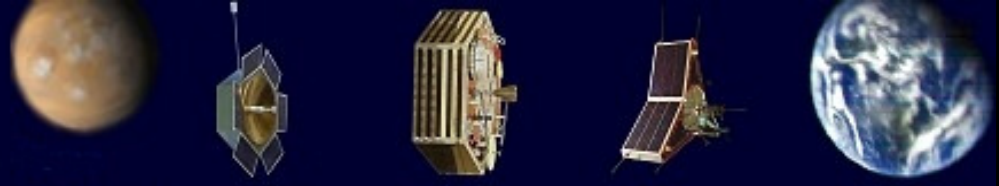


Software: Precision

- Milli Arcseconds, Millimeters (@ millions miles)
- High precision necessary for AMSAT P5A mars mission
- Methods: JPL- und Lunar Ephemerids

Compensation for (excerpt)

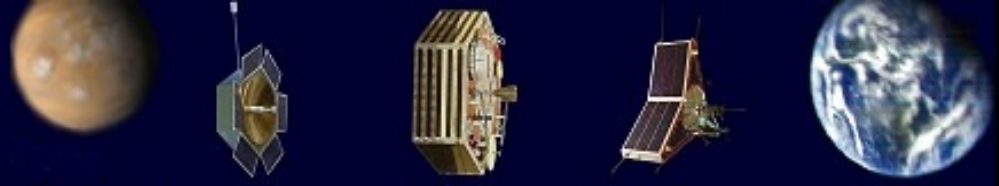
- Signal delay
 - Gravitation
 - Parallax
 - Precession, Nutation, polar movements etc.
-
-



Software: Error Estimation

- Ephemerides calculation: 0.05"
- Error antenna position: 0.05"
- Error clock: 0.2"
- Neglection polar movement: 0.5"
- UT1 rounding: 0.8"
- Refraction: $\sim 5''$ (?)

Beam with: 100" @ 10 GHz for -0.25 dB

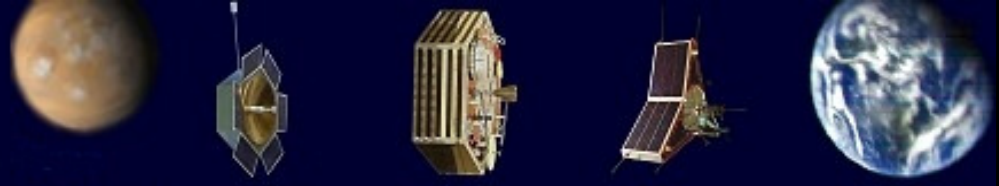


RF System 66' antenna

based on the presentation
„Deep Space Communication“
of Freddy de Guchteneire, ON6UG

*Designer of antennas and transponders
at least for AO-10, AO-13, AO-40*

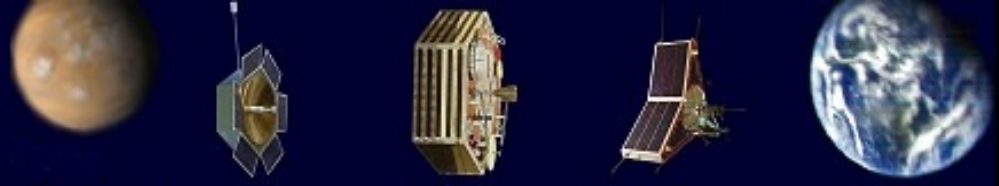




RF System: General

- Projected in 1960's: Rohde & Schwarz
- In theory usable at 8 resp. 10 GHz
- First checkout: TV-Satelliten @ 12 GHz
- Moon noise, moon “grey line”
- Galactic noise sources
- Space probes (8.4 GHz)
- Moon echoes

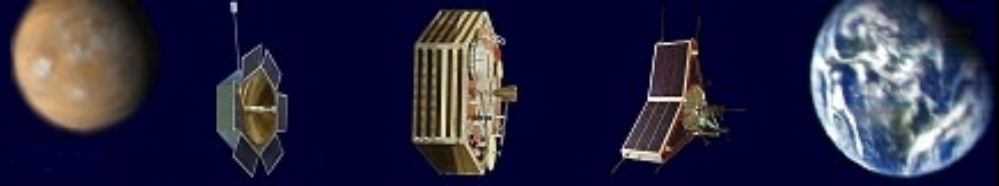
Freddy de Guchteneire, ON6UG



RF System: Technical Data

$D = 20 \text{ m (66')}$, $A = 188 \text{ m}^2$ (~ 2000 square feet)
@ 60% Illumination

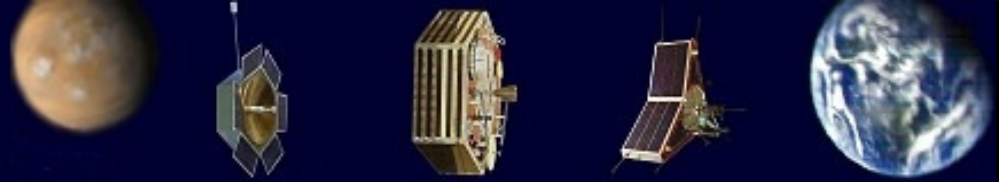
- 2.4 GHz (S Band)
 - $G = 51.8 \text{ dBi}$
 - Beam width
 - 0.8° bei -10 dB
 - 0.42° bei -3 dB
 - 0.13° bei -0.25 dB



RF System: Technical Data

8.4 GHz (X Band)

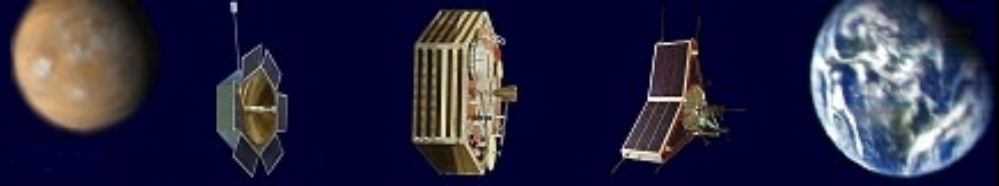
- $G = 62.7 \text{ dBi}$
- Beam width
 - 0.23° @ -10 dB
 - 0.12° @ -3 dB
 - 0.04° @ -0.25 dB



RF System: Technical Data

10.5 GHz (X Band)

- $G = 64.6 \text{ dB}$
- Beam with
 - $0.18^\circ @ -10 \text{ dB}$
 - $0.10^\circ @ -3 \text{ dB}$
 - $0.03^\circ @ -0.25 \text{ dB}$

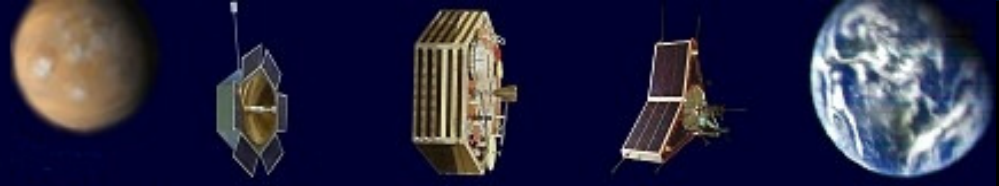


RF System: Sun Noise

- RF < 30 GHz: not a black-body radiator anymore but $S \sim f^{0.8}$
- Typical numbers:

$$dT = \frac{S A}{2 k}$$

Frequency	2.4 GHz	8.4 GHz	10.4 GHz
S	159 SFU	328 SFU	338 SFU
dT	108300 K	223420 K	264280 K
Y	1084	2235	2644
Y	30.4 dB	33.5 dB	34.2 dB

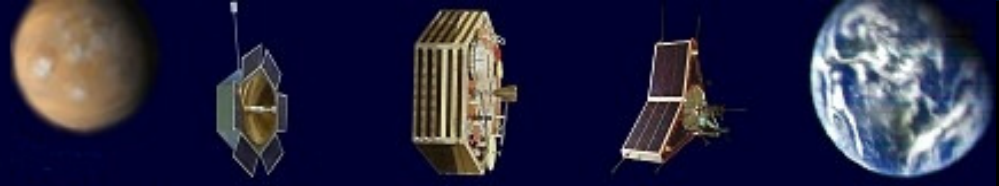


RF System: Moon Noise

- Moon: Black-Body Radiation ~ 200 K

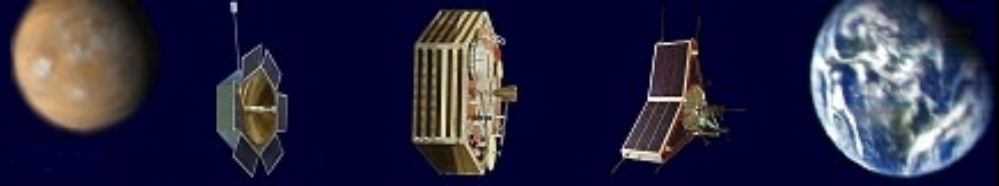
Frequency	2.4 GHz	8.4 GHz	10.4 GHz
S	2120 Jy	26000 Jy	39600 Jy
dT	144 K	1768 K	4042 K

$$1 \text{ Jy} = 1 \times 10^{-26} \text{ W/m}^2/\text{Hz}$$



RF System: Noise from Cas A

Frequency	2.4 GHz	8.4 GHz	10.4 GHz
S	1542 Jy	600 Jy	512 Jy
dT	105 K	41 K	35 K
Y	2,05	1,41	1,35
Y	3,1 dB	1,5 dB	1,3 dB



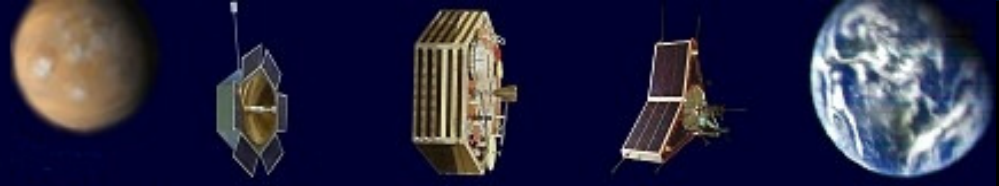
RF System: Receiver Sensitivity

SSB bandwidth, 2.4 kHz

$$T_{\text{sys}} = 100 \text{ K}$$

$$T_{\text{D}} = 1 \text{ s}$$

$$\rightarrow T_{\text{RMS}} = 2 \text{ K oder } S = 30 \text{ Jy}$$



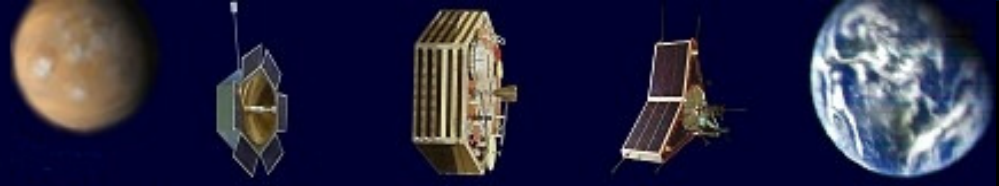
RF System: Receiver Sensitivity

Bandwidth 1 MHz

$$T_{\text{sys}} = 100 \text{ K}$$

$$T_{\text{D}} = 1 \text{ s}$$

$$\rightarrow T_{\text{RMS}} = 0.1 \text{ K oder } S = 1.5 \text{ Jy}$$



RF System: Signal to Noise

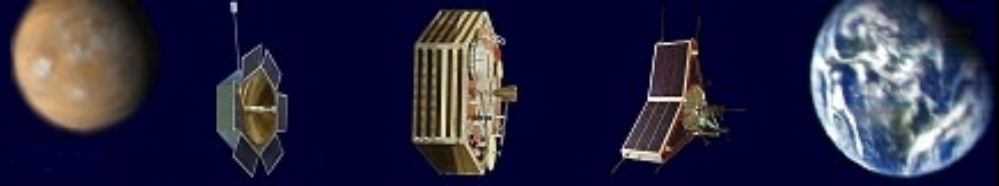
$$\text{SNR} = dT / T_{\text{RMS}}$$

Assumption: 10 dB S/N necessary for detection

$$dT = 10 \times T_{\text{RMS}}$$

@ 1 MHz bandwidth:

$$dT_{\text{Limit}} \approx 1 \text{ K oder } S \approx 15 \text{ Jy}$$



Targets fulfilled - Achievements

- several Mars spacecraft
 - Saturn probe Cassini (700 million miles)
 - Noise sources Cas A, Virgo etc.
 - Moon echoes 10 GHz, 24 GHz
 - Evidence of Stratospheric Scatter, Jet-Scatter @ 10 GHz
 - Voyager-1 (314 dB path loss)
 - *Venus-Echos ?*
-
-



-905 Hz
-0 Hz
+905 Hz
-905 Hz

100% DOWN
CASSIOPEIA

1 dB

TO CASSIOPEIA

Max 14/2/2004

~ 4.5-5 dB,
CIRC Feed Long W.G.

CTR 1.2725 GHz

SPAN 100 kHz/

RES BW 3 kHz

VF .3

REF -40 dBm

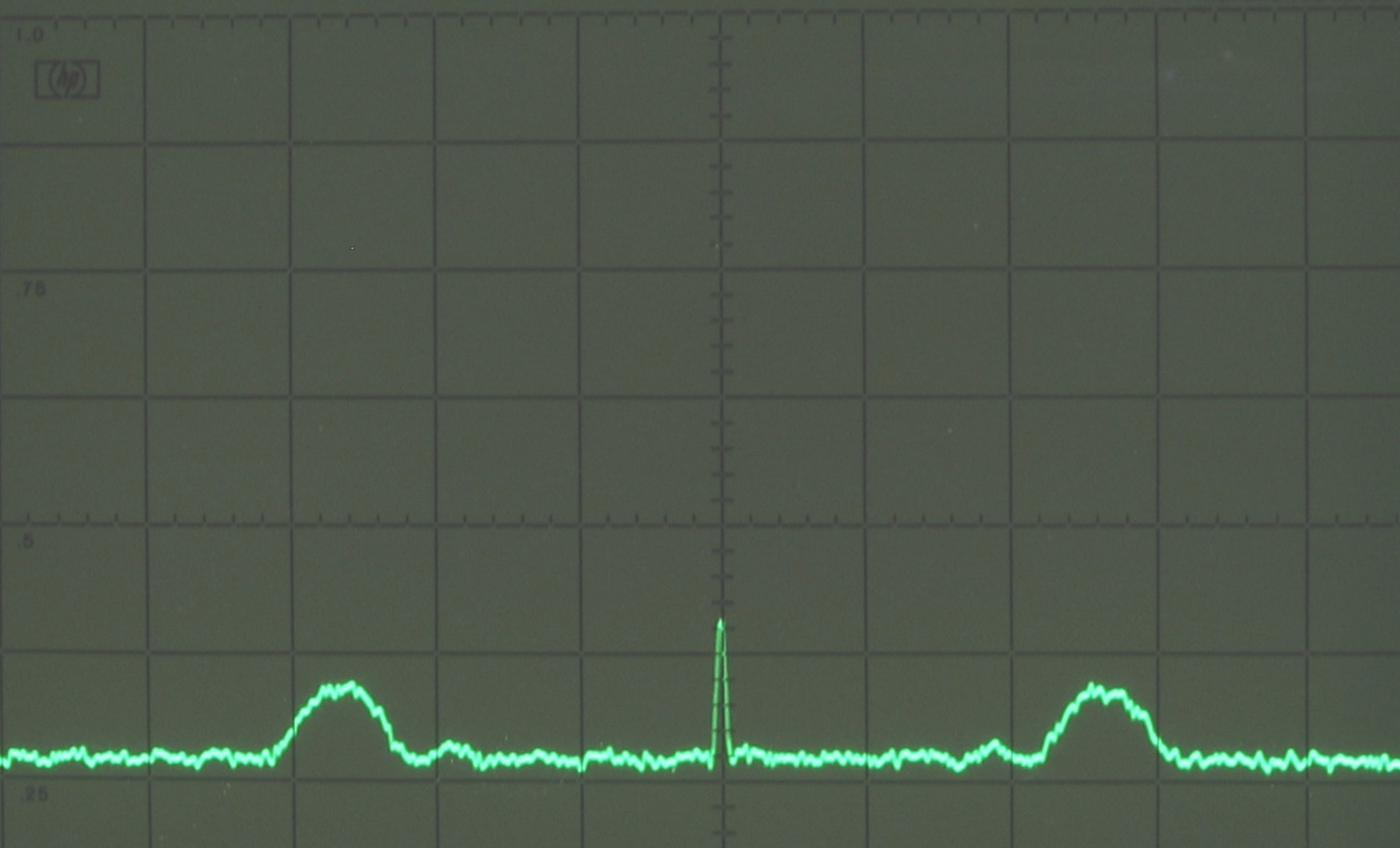
10 dB/

ATTEN 0 dB

SWP AUTO

D AVG

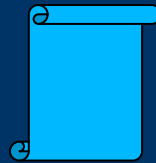
REFERENCE LEVEL



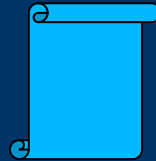


Achievements - Media

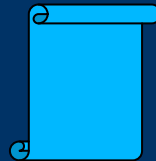
EME 10 GHz 50 W:



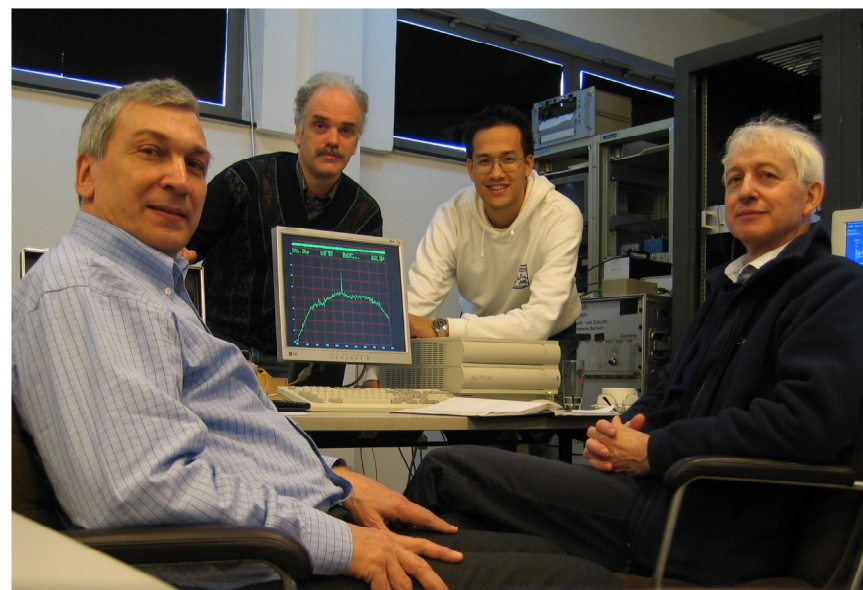
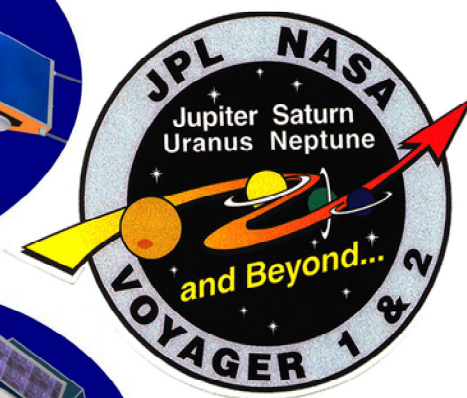
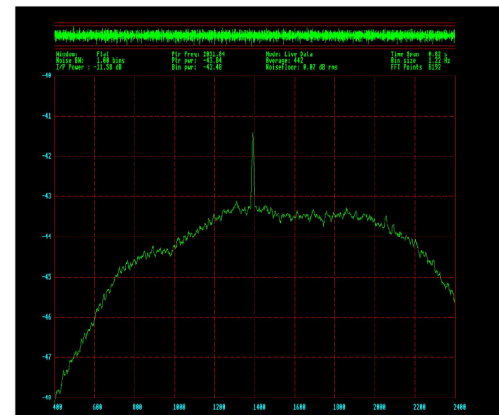
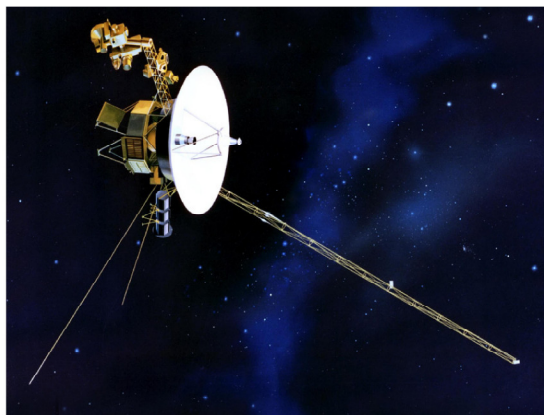
EME 10 GHz 200 W:



EME 10 GHz 1 kW:

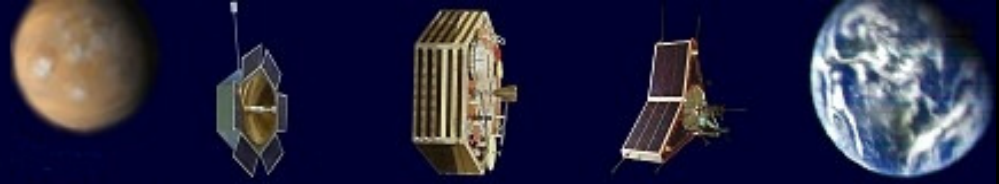


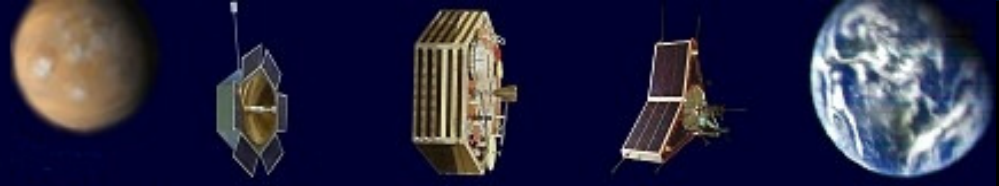
First reception of VOYAGER 1 by radio amateurs
March 31st, 2006 0826UT @14.7 billion km (98.7 AU)



ON6UG, DL1YDD, DH2VA, G3RUH







Dictum

„We cannot afford turning around every stone we catch sight of to look for possible worms. In case a worm would thwart us, we will scrunch it”.

Karl Meinzer, DJ4ZC, Project Leader P5A





Was it worth the effort?

Definitively: Yes, because:

- learned **very** much, fantastic team
- reputation of AMSAT-DL largely enhanced (e.g. JPL)
- door opener e.g. at DLR → immediate influence on P-3E
- we need it
- it was **fun**!

